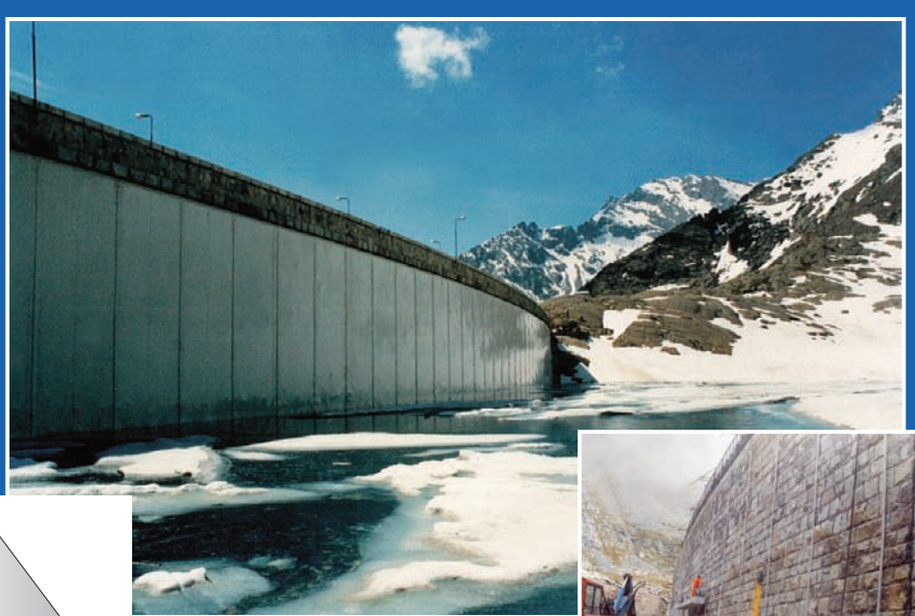
carpi

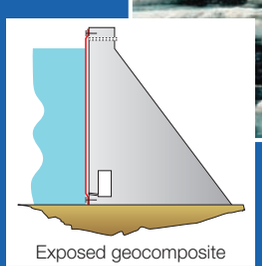
Since 1963

WATERPROOFING SPECIALISTS AND CONTRACTORS
WITH GEOMEMBRANES

CONCRETE AND MASONRY DAMS

WATERPROOFING OF THE UPSTREAM FACE





110+ dams of all types (as of 2011)

Providing Dry and Underwater Installations

C O N C E P T

The CARPI SYSTEM is a patented system for waterproofing and draining the upstream face of all types of dams and providing protection from the deterioration phenomena caused by seepage of reservoir water into the structure.

The upstream face of Cignana dam, deteriorated by freezing and thawing cycles, before rehabilitation.

Primary benefits of the CARPI SYSTEM include:

- Stop water seepage and deterioration
- Restore impermeability of the deteriorated dam face
- Reduce uplift in the dam body
- Restore safety factors to original values
- Dehydrate the dam body from infiltrating water.

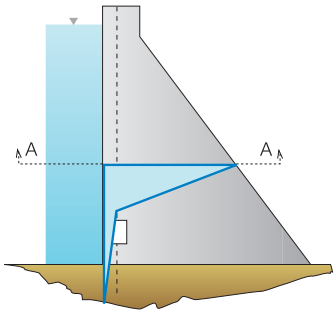
Cignana dam rehabilitated with CARPI SYSTEM (1988). The geomembrane system in 2011 is in full service.

The above benefits are achieved by installing a continuous impermeable barrier from the crest to the heel of the dam. The barrier can be connected with the foundations and the grout curtain. A continuous face drainage system installed between the barrier and the dam face collects and discharges the water from seepage and dehydration.
The CARPI SYSTEM impermeable water barrier consists of an exposed flexible synthetic geocomposite (impervious geomembrane + anti-puncture geotextile). Linear anchorage of the geocomposite to the upstream face of the dam is made by mating pair of stainless steel vertical patented profiles.
Watertight perimeter anchorage avoids by-passing of the barrier by the reservoir water.
Since the entire surface of the geocomposite is not glued to the dam face, the system allows drainage of the seepage water and dehydration of the dam body from water that has already infiltrated. A perimeter collection system at the heel of the dam allows discharge of the drained water.

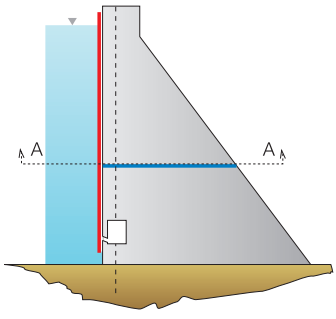
In the two figures below we present uplift diagrams for the traditional gravity dam with drains and with exposed CARPI drained geomembrane system.

Comparing uplift at current section of dam

Uplift at current section of dam without geomembrane and 100% drilled drains efficiency.



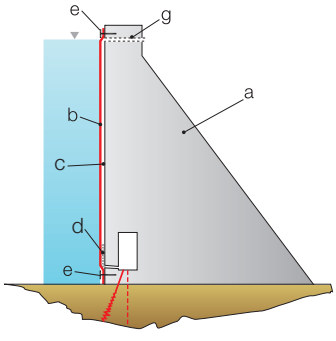
Uplift at current section of dam with Carpi exposed drained geomebrane system.



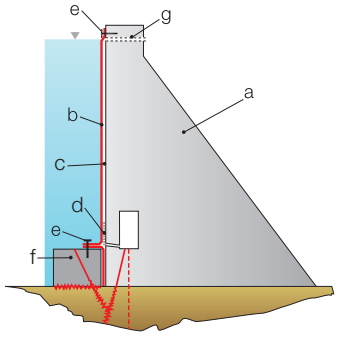
CARPI drained system

Typical cross sections

Without new grouting beam

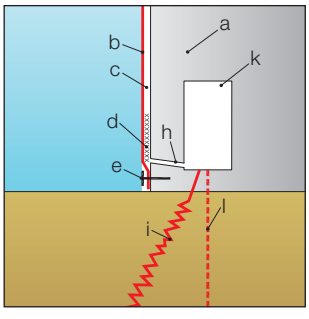


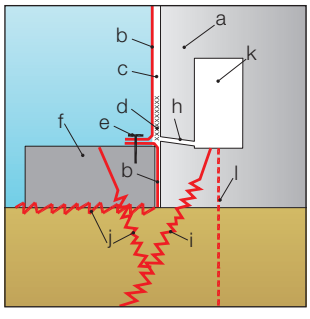
With new grouting beam



a) Dam body
b) CARPI waterproofing liner
c) Vertical anchorage and face drainage for geocomposite
d) Perimeter drainage collection system
e) Perimeter seals
f) New grouting beam (if required)
g) Ventilation pipe

Detail at heel

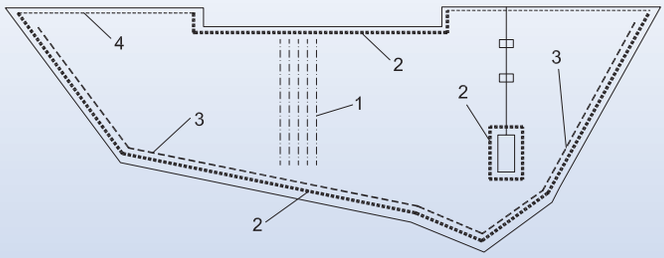




h) Drainage discharge
i) Grouting curtain
j) Contact grouting
k) Inspection gallery
l) Dam drains

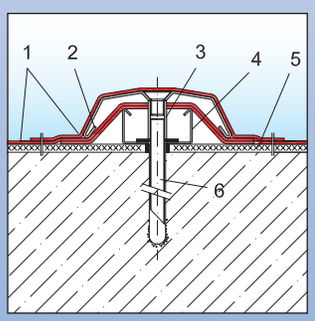
COMPONENTS

All components are manufactured in the controlled environment of a factory to assure uniform quality.

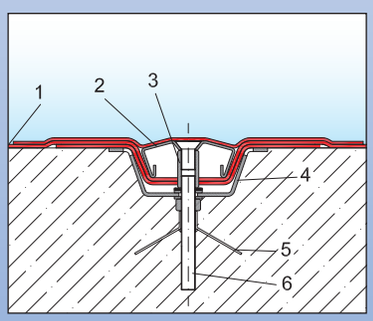


1. Vertical anchorage on upstream face
2. Watertight submersible perimeter seal
3. Drainage water collection
4. Watertight non submersible perimeter seal

The upstream face anchorage is a CARPI patent, as also cited in CIGB - ICOLD Bulletin 135.



1. *PVC geocomposite and PVC geomembrane strip*
2. *Tensioning profile*
3. *Connector*
4. *Lower profile*
5. *Drainage geonet*
6. *Anchor*

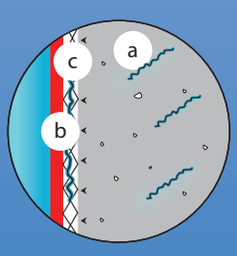


1. *PVC geocomposite and PVC geomembrane strip*
2. *Tensioning profile*
3. *Connector*
4. *Embedded profile*
5. *Anchor swing*
6. *Anchor*

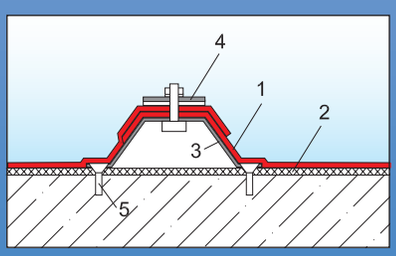
From “Geomembrane Sealing Systems for Dams - Design principles and review of experience” - Bulletin 135 - CIGB - ICOLD - 2010

The anchorage system creates a ventilated gap behind the PVC geocomposite, where drainage can occur at ambient pressure. Water already in the dam body is extracted and discharged. Decrease in water content is beneficial in case of Alkali-Aggregate Reaction (AAR).

Installation can be performed in the dry or underwater, with patented anchorage profiles developed for underwater installation.



a. Saturated concrete
b. SIBELON® geocomposite
c. Drainage gap



1. SIBELON® geocomposite
2. Drainage geonet
3. Lower profile
4. Flat profile
5. Anchor

1 - The vertical profiles assemblies anchor the waterproofing liner to the upstream face of the dam, and pre-tension it to eliminate wrinkles and slack areas.

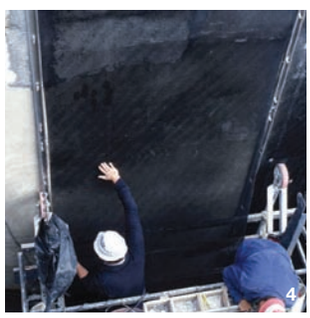
2 - The vertical profiles also serve as free-flow conduits to convey drained water to the collection and discharge system at the heel of the dam.

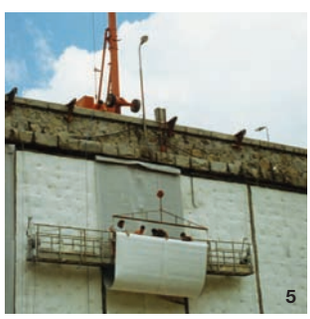
3 - The new grouting beam sandwiches the membrane liner waterproofing the upstream face.

4 - The continuous face drainage consists of the fastening profiles and of the geotextile attached to the impermeable synthetic geomembrane. Highly transmissive geonets (pictured) enhance water conveyance to bottom collection.

5 - The waterproofing liner is a geocomposite, SIBELON® CNT, consisting of a flexible impermeable PVC geomembrane, coupled to a geotextile during the manufacturing process. The geomembrane is UV resistant and suitable for long term exposure in highly aggressive environments. On the pictured dam, a thick geotextile is an additional anti-puncture protection from the rough masonry surface.

6 - The waterproofing liner is manufactured in sheets, custom designed for each project to eliminate/minimise transversal joints. Adjoining sheets are heat-welded.





The CARPI patented systems are used to waterproof the entire face of the dam, or to waterproof localised areas such as cracks or failing joints.

7 - The coupling of the two patented vertical profiles achieves fastening and tensioning of the waterproofing liner and drainage of water to the free-flow discharge conduits.

8 - Geomembrane cover strips are welded over the vertical anchorage profiles assembly to the waterproofing liner to insure a complete watertight seal.

9 - The drainage collector can be a strip of geonet...

10 - ... or it can be installed in a trench at the heel, or in a new beam, or consist of a specially designed drainage profile externally anchored to the upstream face, as pictured.

11 - The face drainage system picks up any seepage resulting in dry drilled drains and gallery. Pictured is total discharge from a >15,600 m^2 upstream face, water head 65 m. Drainage discharge can also be made downstream or in the reservoir.

12 - Pictured is total discharge from a 8000 m^2 upstream face, water head 70 m. Additional information on performance of the system can be obtained by piezometers installed behind the waterproofing liner.

13 - Piano Barbellino dam (66 m), Italy 1987.

14 - Perimeter anchorage along the lower perimeter of the dam, at spillways, outlet works, intake structures and protruding appurtenances from the upstream face, is watertight and has been tested to resist water heads up to 250 m. All profiles and anchorage fittings are in stainless steel.

15 - Installing a double perimeter seal at bottom allows reducing the head on the primary seal that confines the waterproofing system of the upstream face, and separating water drained from foundations from water drained from the upstream face.

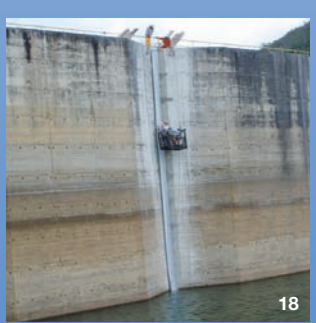
16 - Divers at the air/water interface installing the perimeter seal anchor bolts along foundation.

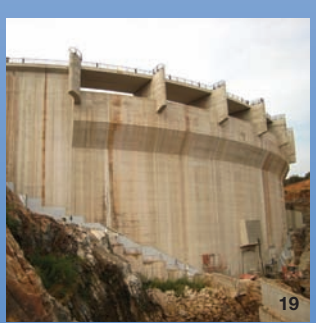
17 - Watertight penetrations are installed at all geomembrane crossings such as at the supports for the gates.

18 - The CARPI SYSTEM has also been used to waterproof only defective joints, or cracks. The geocomposite is attached with support to avoid intrusion in the joint/crack under high water heads (Usina da Pedra dam, Brazil).

19 - Waterproofing of joint plinth/upstream face, where large opening is expected at first impoundment (Melonares dam, Spain).

20 - Toules double curvature arch dam (86 m), Switzerland 2010: waterproofing of fissured area.

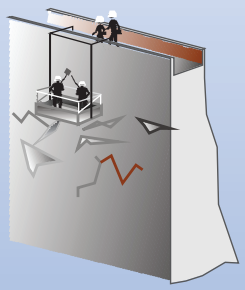




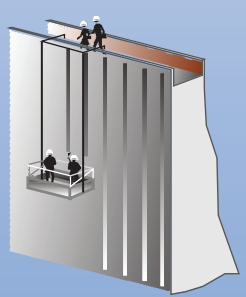
System Design: each CARPI SYSTEM is custom designed for the specific project. Procedures and materials are selected dependent on the type of dam and upstream facing , on degree of deterioration of the upstream face, on severity of environmental conditions, on the possibility of seismic events, and on the desired seepage results.

INSTALLATION
Procedure for a standard intervention

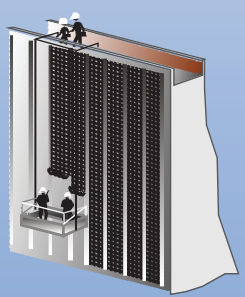
1 - The existing surface.



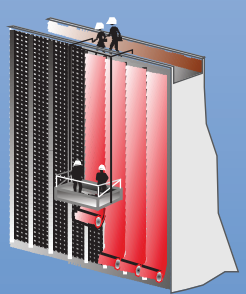
2 - Surface preparation (removal of loose material).



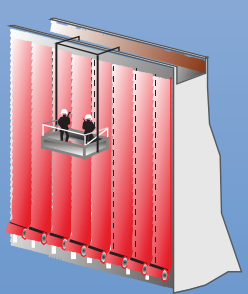
3 - Installation of vertical anchorage and face drain profile.



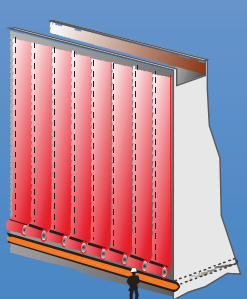
4 - Installation of the high transmissivity drainage layer (geonet, optional).



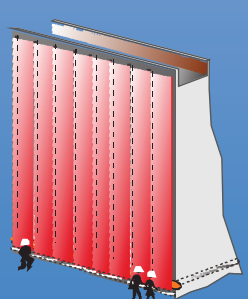
5 - Installation of the waterproofing geocomposite.



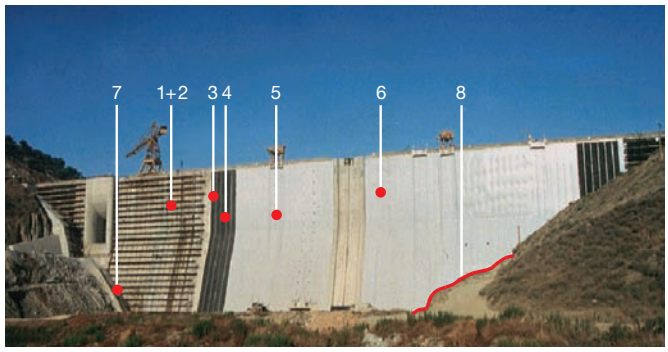
6 - Anchorage and tensioning of sheets.



7 - Perimeter drainage collection and discharge system.



8 - Installation of the watertight perimeter anchorage.



Pracana dam - General installation scheme.

1-2 Surface Preparation
The intervention begins with preparation of the surface of the upstream face to ensure sufficient subgrade exists to securely anchor and seal the profiles. Since the system can be installed on fairly rough surfaces, removal of all loose material and subsequent patching of the most severely damaged areas are usually sufficient. In the case of extremely rough surfaces, a thick geotextile can be installed against the dam face as an additional anti-puncturing and transition layer.

3 Installation of Vertical Anchorage Profiles
The intervention continues with installation of the internal vertical profiles on the face of the dam. Profile locations are determined during the system design to eliminate conflicts with construction joints or other features of the dam. The profiles are fastened to the dam face by expansion and/or chemical anchors.

4 Installation of the Continuous Surface Drainage Layer
When a higher drainage capacity is required, an additional layer of geosynthetic material (geonet, geotextile or other synthetic material with high transmissive properties) is installed against the upstream face of the dam. The material is anchored to the dam by impact anchors placed at predetermined location.

5-6 Installation and Anchorage of the Waterproofing Liner
The liner is supplied in rolls manufactured in a plant. Each roll is first anchored at the crest, then deployed and aligned, then anchored and pre-tensioned from both edges using the external vertical profiles. Tensioning smoothes the material and removes any wrinkles or sagging. The overlap of adjoining sheets is welded using hot air welders, followed by installation of the perimeter profiles. Finally, the external vertical anchorage profiles are covered with geomembrane strips and hot air welded to the waterproofing liner.

7 Drainage Collection and Discharge system
The drainage collection system is installed above the watertight perimeter anchorage at the heel of the dam, between the waterproofing liner and the dam face. The system consists of a free-flowing collection pipe or drainage geonet connected to transverse conduits that discharge into the inspection gallery or at the downstream face of the dam. The system can be divided into sections to improve the accuracy of monitoring the source and quantity of infiltrating water. The system can be further improved with the addition of an optical fibre cable or electrical sensor system, which allow very precise monitoring of the efficiency of the waterproofing liner.

8 Installation of the Perimeter Anchorage Sealing Profiles
The installation of the watertight perimeter anchorage is one of the most critical aspects of the system. The greatest care is taken to ensure absolute watertight integrity especially at joints or fissured zones, where water could by-pass the system and infiltrate behind the liner. Expansion and/or chemical anchors secure the perimeter profiles, which in turn compress the gasket material (for surface smoothing and for distribution of the compressive stress) and waterproofing liner against the dam face.

21 - Installation is made from travelling platforms suspended at crest.

22 - Travelling platforms can be designed to allow installation on complicated geometries.

23 - Scaffoldings are used where access by platforms is not possible. Transport of installation equipment and materials by helicopter has reasonable cost due to light weights and small volumes involved.

24 - Permanent shelters can be used if installation must be carried out in harsh conditions with persistent bad weather.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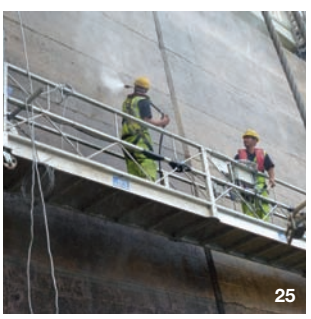
25 - Hydro-jetting to remove loose material.

26 - To minimize surface preparation on large cavities, high bearing capacity geogrids are used to support the waterproofing liner over the cavities.

27 - Example of different anti-puncture geosynthetics depending on the roughness of the existing surface: thick geotextile (white material) on rough masonry surface, geonet (black material) on concrete surface.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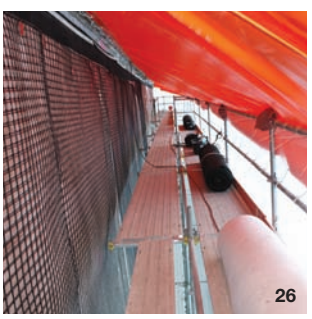
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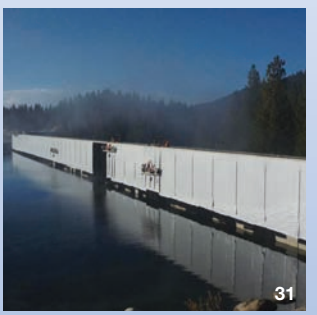
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28 - Placement of waterproofing liner at new grouting beam.

29 - Optical fibre cables signalling the area of a leak placed at bottom drainage collectors.

30 - Construction can be staged in separate campaigns to accommodate operational/financial requirements (Bouillouse, France, from 1996 to 2000).

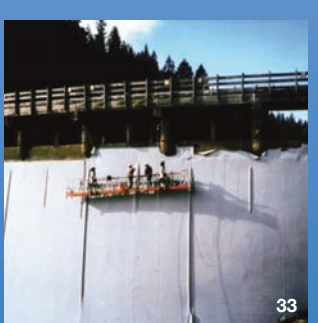
31 - Staged construction carried out above water level with reservoir in operation (Shaver Lake dam, USA 2010 to 2012).


32

32 - Silvretta, Austria 2010 and 2011: staged construction to meet schedule of overall rehabilitation works.

33 - The spacing of the tensioning profiles is calculated base on uplift loads. Pictured is closer spacing at top section exposed to wind, and larger spacing in section permanently underwater.

34 - The anchorage system allows achieving a perfectly tense PVC geocomposite on complicated geometries.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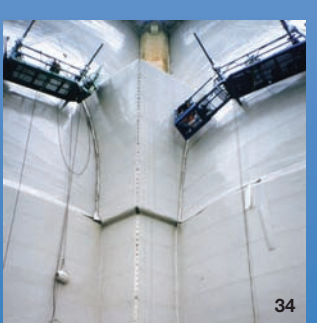
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REFERENCES

ICOLD, the International Commission on Large Dams, in its Bulletins N. 78 “Waterproofing geomembranes for dams”, N. 107 “Concrete dams - Control and treatment of cracks”, and N. 135, “Geomembrane sealing systems for dams”, discusses a series of installations made by CARPI of the CARPI SYSTEM as an example of functional rehabilitation of the upstream face of dams and of local deteriorated or crucial areas. The Research Institute of Hydro-Québec, IREQ, has published a research report stating the CARPI SYSTEM is the best system for rehabilitation of concrete dams in cold climates.
The US Army Corps of Engineers Waterways Experiment Station awarded a research project to CARPI to develop an adaptation of the CARPI SYSTEM for underwater installation. The two-phase project demonstrated feasibility of underwater installation. In 1997, a full underwater installation of the CARPI SYSTEM was accomplished on Lost Creek dam in California. The project was granted in the USA the 1998 West Region Award of Merit by the Association of State Dam Safety Officials (ASDSO), a Hydro Achievement Award for Technology Solution from the National Hydropower Association, the 1999 Federal Laboratory Consortium Award of Merit through the U.S. Army Corps of Engineers and the 2000 International Geosynthetics Society (IGS) Award.
Between 1970 and 2011, CARPI has successfully installed the CARPI SYSTEM on more than a hundred dams in Europe, Americas, Asia and Africa. The flexibility of the system has allowed intervention on all types of dams at widely varied altitudes and latitudes, including extremely aggressive environments and underwater.

BENEFITS

Installation of the CARPI SYSTEM on dams achieves the following:

- Continuous waterproofing of the upstream dam face, including expansion and construction joints and cracks
- A new continuous face drainage system
- A barrier to water infiltration in the event of formation of new cracks
- Reduction of uplift
- Dehydration of the dam body
- Protection from freeze-thaw cycles
- Protection from pure or sulphonated water
- Protection of the dam body in case of alkali-aggregate reaction
- An intervention that does not alter the structure of the dam
- An intervention that is environment friendly, no large construction equipment, no pollution
- An intervention that can be accomplished underwater, thus minimizing impact on dam operation and on the environment.


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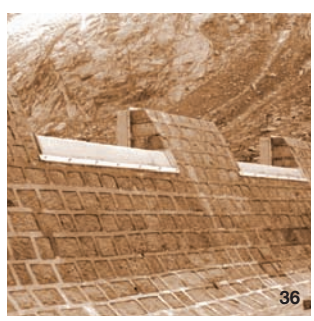
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35 - SIBELON® CNT geocomposite can resist impact of thick ice covers. Ice does not stick to the geomembrane, which is therefore not affected by shear forces.

36 - SIBELON® CNT geocomposite installed on spillways. No damage by floating debris has ever been reported.

DURABILITY AND PERFORMANCE

All elements of the system are designed to guarantee > 50 years service in sections permanently exposed to water.
Accelerated aging tests in the laboratory showed SIBELON®, the impermeable synthetic geocomposite developed by CARPI, to have a service life measured in hundreds of years. Those results were further confirmed by laboratory testing conducted on samples of SIBELON® liners exhumed from more than a dozen installations dating back to 1970.

The CARPI SYSTEM is a well established dam waterproofing system because of its proven:

- Durability which prolongs dam life by decades
- Modular design resulting in quick installation in all climates and simple mob/demob
- Adaptability to rough subgrade reducing installation time and costs and
- Effective waterproofing which dehydrates the dam and arrests deterioration.

Installations have varied from medium height dams to dams exceeding 170 meters, from alpine to the equator, from heavy ice exposure to high ultraviolet exposure, will all installations still performing. Owners, designers and contractors have provided written recommendations testifying to the dependability, longevity, and low maintenance costs associated with the CARPI SYSTEM. Our system has more than 2200 cumulated years of service life with owners experiencing zero repair costs.

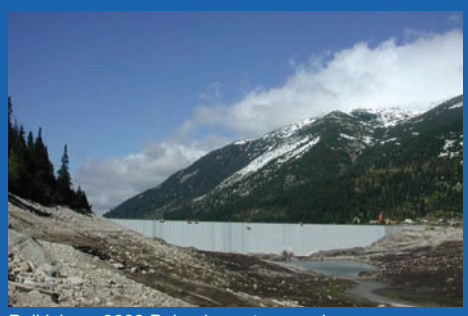
Publino dam - Italy.

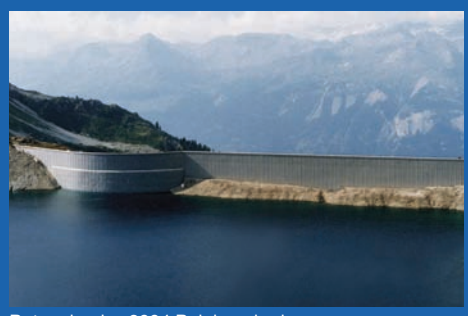
Balambano dam, Indonesia.


37

37 - Ice block sliding down along the SIBELON® CNT geocomposite, no damage by ice or debris.


Lago Nero - 1980 Italy, hydropower


Beli Iskar - 2002 Bulgaria, water supply


Butgenbach - 2004 Belgium, hydropower


Kadamparai - 2005 India, hydropower


Illsee - 1996 Switzerland, hydropower


Covâo do Ferro - 2005 Portugal, multipurpose


Cignana - 1988 Italy, hydropower


Silvretta - 2010/2011 Austria, hydropower


Waldeck - 2008 Germany, pumped storage


Migoelou - 2008 France, hydropower


Scais - 1997 Italy, pumped storage


Shaver Lake - 2011 USA, hydropower

Lost Creek - 1997 USA, multipurpose. Winner of:

- 1998 West Region Award of Merit from the Association of State Dam Safety Officials (ASDSO)
- Hydro Achievement Award for Technology Solution from the National Hydropower Association
- 1999 Federal Laboratory Consortium Award of Merit through the U.S. Army Corps of Engineers
- 2000 International Geosynthetics Society (IGS) Award


Chambon - 1994 France, hydropower

Gem Lake - 2007 USA, hydropower. Winner of:

- 2008 National Rehabilitation Project of the Year Award of Merit from the Association of State Dam Safety Officials (ASDSO)


Brändbach - 2000 Germany, water supply

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Underwater installation - 1996 USACE research

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